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Wear damage of carbon-polyethylenimine composite

Ahmed HEBBAR and Noureddine MAHMOUDI

Laboratory of numerical and experimental modelling of the mechanical phenomena
B.P. 882-RP- University of Mostaganem, 27000 Mostaganem - ALGERIA

Abstract

Wear resistant composite offer reliability and value in a wide range of wear-sensitive applications. These specialty compounds give designers and processors tremendous flexibility and significant benefits over composite. After wear, the composite's roughness as brass counterface increases. At low loads, polyethylenimine layer gets removed. At higher loads, some of the fibers have cracked and the gap is occupied by brass debris. Brass powders are accumulated in some portions on the composite surface. The debris contains brass fragments, carbon fiber fragments as well as polyethylenimine material. At high loads some of these debris gets compacted between the fibers.

Keywords: Carbon-polyethylenimine composite, roughness, wear damage;

1. Introduction

Wear is progressive loss of material due to relative motion between two surfaces [1]. Composite materials in general are being used increasingly in wear related applications [2]. Carbon fiber-polyethylenimine matrix composite have a wide application in industry. It offers a number of advantages like high specific strength and modulus, ease of fabrication and ability to tailor the component design [3]. Once the composite is used for structural applications it is inevitable that they experience friction and wear conditions. Under such conditions the material damage appears in the form of matrix cracking, interface debonding, delamination and fiber breaking. Although the wear damage can start in the initial stages of life, the components can be used for long before the component needs to be rejected. Some times the cause of rejection may be different than wear damage in the form of increased surface roughness or loss of appearance. Since damage initiation and their spread in the composite component is more complicated (due to their heterogeneity) than in the monolithic material, their investigation and understanding is useful in designing the composite structure. In this investigation, wear damage on the carbon- polyethylenimine composite when it is made to slide against a brass plate at different loads is reported.

* Corresponding author. Tel.: +213 664 59 74 61; fax: +213 45 30 10 16.
E-mail address: hebbar_a@yahoo.fr.

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2. Materials and Experiments

The material used for tribological study is carbon polyethylenimine laminated composite unidirectionnel. Thickness of the sample was 6mm. Carbon fibers were of continuous type with diameter 10 to 12 µm. Figure 1 shows fiber orientation and uniformity in their alignment. Samples of size 6mmx6mm were carefully cut from the sheet and these pieces are used for studying the wear damage. Wear damage is studied using a pin on disc machine with a commercial brass (alpha brass) disc. The brass disc had following composition: 93.8wt%Cu, 1.35wt%Pb, 4.8wt%Zn.The hardness of the brass disc is 105 to 108Hv (13Kg load). RPM was 477 and sliding time 30min. The load used is 1, 2 and 3kg. Orientation of the fiber with respect to sliding direction is approximately 45 degree. Schematic of this orientation is shown in figure 2. Since roughness of the mating surfaces affects wear damage [4], the roughness of the brass disc and composite surface is measured using a Taylor Hobson Profilometer. The brass plate had initial roughness of 0.0283µm R_a, 0.7454µm R_t, 0.1569µm R_z and the composite had a roughness R_a = 0.7634µm, R_t = 6.7921µm, R_z = 3.4567µm (refer table.1). Roughness of the composite surface after testing is again measured. Wear damage is also measured as weight loss. The damaged surfaces are examined with a scanning electron and the friction and wear mechanisms are studied. Tests were conducted in normal atmosphere.

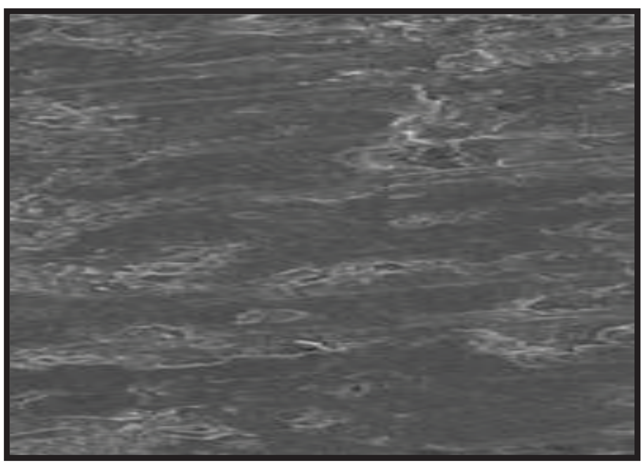

Fig. 1. Fiber orientation and uniformity in their alignment (X 500)

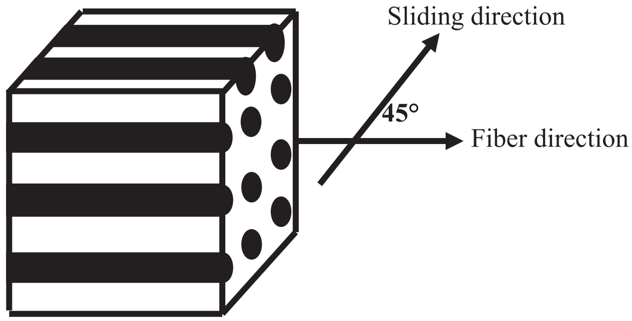

Fig. 2. Orientation of the fiber and sliding direction

3. Results

Table 1 and 2 shows wear damage in the form of roughness and weight loss. We see that roughness of the composite surface and brass counterface increases after wear. But wear (weight) loss as in table.2 does not show any trend. Figure 3 shows a low magnification micrograph showing the morphology of the composite surface after wear. We see that brass powders are accumulated in some portions on the composite surface. Other regions on the composite surface have relatively small amount of brass powders. Figure 4 shows a high magnification micrograph from figure 3 showing isolated fine brass particles. The micrograph shows that some of the fibers have cracked and the gap is occupied by brass debris. The entrapped debri particles are very fine (submicron size). Some of the fibers have got shifted laterally and we can see some amount of matrix–fiber debonding along the length. Figure 5 shows another region from figure 3 where huge quantities if debris are seen. We see varieties of shapes (flat, elongated, etc.) for debris. A careful observation of these particles shows that some of these particles are turned into loops and the edges of some particles show indications of fracturing. Along with the brass particles we have some broken carbon fiber pieces also.

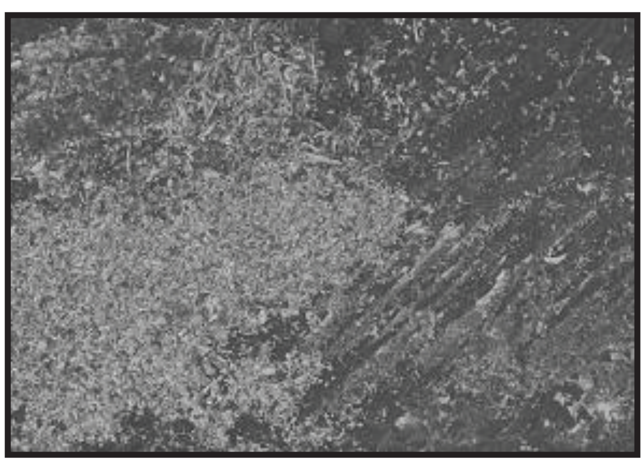

Fig. 3. Morphology of the composite surface after wear (X300)

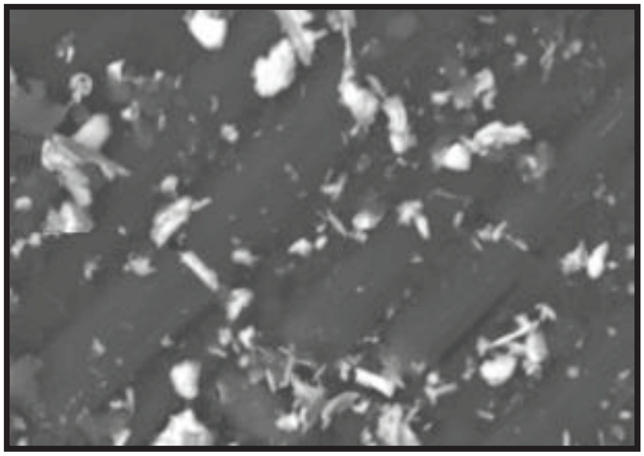

Fig. 4. High magnification micrograph from figure 3 (X1000)

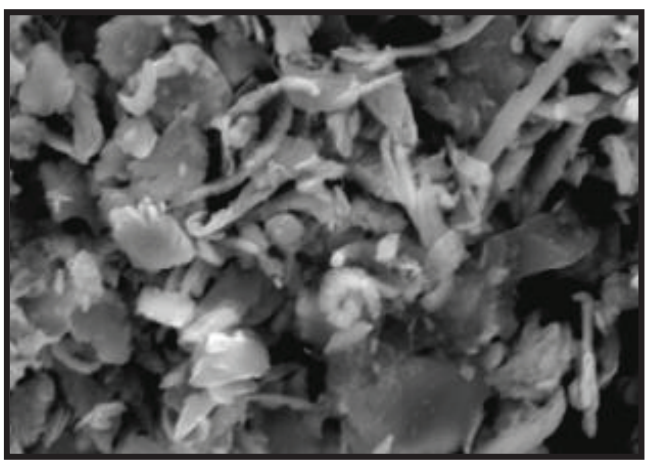

Fig. 5. Another region from figure 3 (X1100)

Table 1 shows the results of roughness measurement on the brass plate and composite sample before as well as after the test and we can see that the roughness of the plate and sample has considerably increased after the test.

Material	Before test	After test (um)
Brass plate	R_a=0.0283µm, R_t=0.7454 µm R_z=0.1569 µm	R_a=0.1996 µm R_t=8.3549 µm R_z=0.9389 µm
Composite sample	R_a=0.7634µm R_t=6.7921µm R_z=3.4567µm.	R_a=0.8010µm R_t=10.285 µm R_z=5.351µm

Table 2 shows wear damage in the form of weight loss of composite sample.

Load (Kg)	1	2	3
Weight loss, milligrams	10.3	19.7	124.7
Specific wear rate (mm²/N)	$2.64 * 10^{-7}$	$2.54 * 10^{-7}$	$8.57 * 10^{-7}$

Figure 6 is a micrograph showing the composite surface worn under high load conditions (3Kg load). We see that wear debris are collected in a distributed fashion. Figure 7 is a magnified view from figure 6. It clearly show that debris are freely arranged (isolated debris) as well as compacted between the fibers. Indications of fibers fracture is much more than that seen in the sample with 2Kg load. Also carbon fibers in this sample are more clearly exposed compared with the sample with 2Kg load.

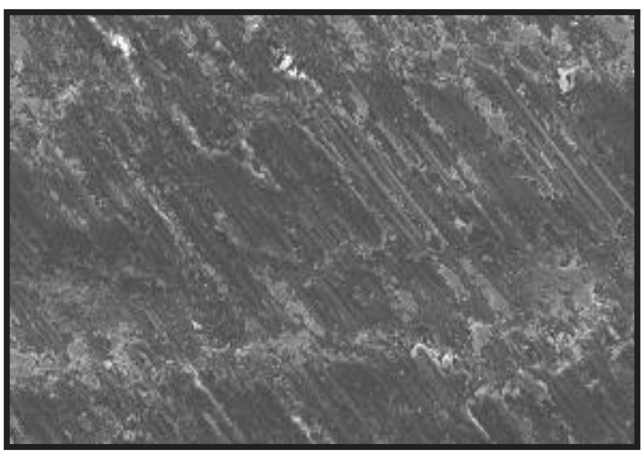

Fig. 6. Micrograph showing the composite surface worn under high load (X200)

Figure 8 is a magnified region from figure 7. The microstructure clearly shows brass debris between exposed carbon fibers. Most of the debris are sub-micron size. Occasionally coarse debris are visible. Figure 9 is another region from figure 7. In this case we see that brass debris and carbon fiber pieces mixed together and pressed.

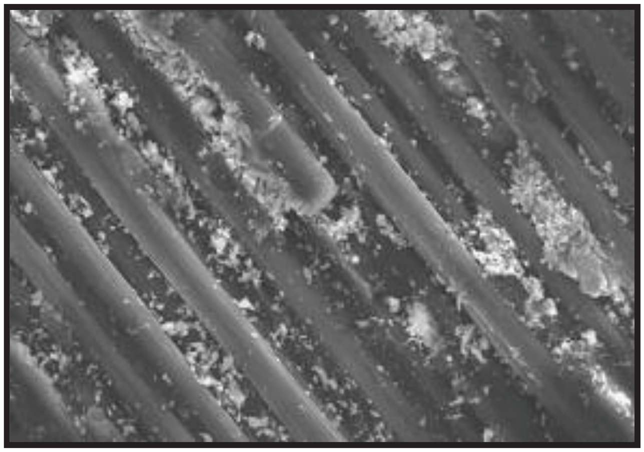

Fig. 7. Extension of figure 6 (X1000)

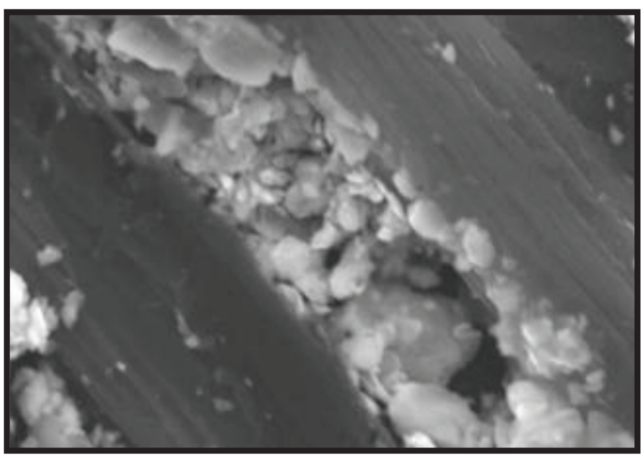

Fig. 8. Extension of figure 7 (X5000)

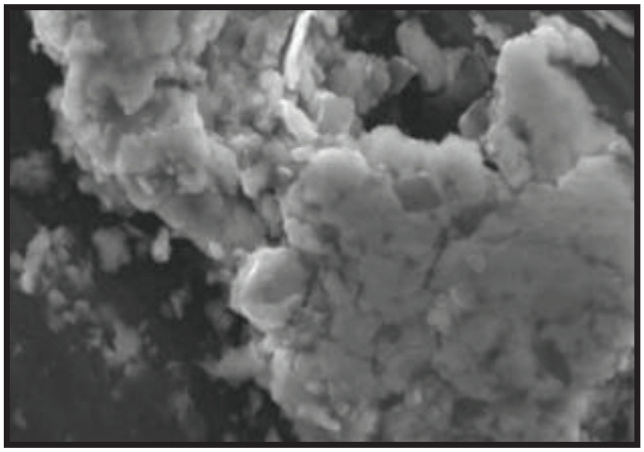

Fig. 9. Other region expanded in figure 7 (X5000)

4. Discussions

The damage of two counterpart surfaces during sliding depends on the type of mating surfaces, temperature, relative hardness, amount of asperity contact and their behaviour during external loading and sliding conditions [5]. This is true for any type of materials in combination (metal-metal, metal-ceramic, metal-polymer and other combinations). Since, our surfaces are metallic (brass disc) based and polymer (polyethylenimine matrix) based, adhesive interaction between them is negligible. In such contacts, the resistance for sliding comes because of the interpenetration of asperities, real contact area, deformation behaviour of asperity bodies in contact and local temperature. For a given loading condition, the roughness factor greatly influences the value of real area of contact. Asperities on the surface acts as abrasives [6].

Our base plate (brass) is a homogenous material and we expect mechanical property to be same everywhere. In contrast, the pin (composite) is heterogeneous in mechanical properties. We have hard and stiff carbon fibers and soft polyethylenimine matrix material. During initial contact (at low load) asperities of brass plate will penetrate the polyethylenimine in the composite. These micro-contacts will cause abrasive action. This is schematically shown in figure 10. The penetration depth will be relatively small. In other words tip of larger asperities will penetrate the polyethylenimine resin. During sliding there will be ploughing action leading to removal of polyethylenimine layer on the surface [7]. Part of the material removed comes out as wear debris [7]. This exposes carbon fiber (which was below the polyethylenimine resin). As sliding continuues we have asperities of brass between exposed carbon fibers. As brass asperities come in contact of carbon fibers, the ploughing action will stop. Because of the relative strengths of brass and carbon fibers, brass asperities undergoes deformation and when it is high asperities will get fractured and will act as third body (along with the removed polyethylenimines), in addition to composite and brass plate in action. Since counterface and composites are oriented at 45 degrees the debris from brass must be by cutting action, as suggested by Torrance [8]. The brass debris in micrograph (figure 5) also shows sharp edges suggesting that majority of them have formed due to cutting action.

At higher loads, the individual micro-contacts will be of larger size and even sometimes adjacent micro-contacts can merge. This leads to increased severity of sliding conditions. This is also shown by the increased roughness value and microstructural features.

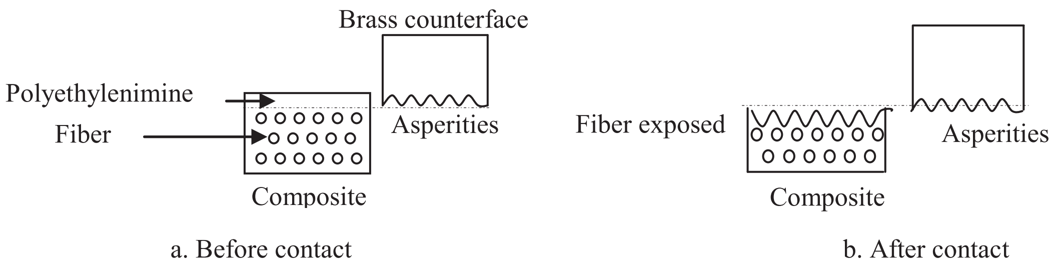

Fig. 10. Contact between composite and brass counterface

The microstructures does not show any side ridging and hence the efficiency of material removal is quite high. The actual magnitude of material removal depends on the degree of material removal [7]. As the composite material is heterogeneous the material removal rate also varies during sliding. Initially the load is carried by brass- polyethylenimine and in later stages mainly by bass-fiber and to an extent brass-polyethylenimine contacts. This basically means that wear process is not stationary [7]. At the later stages of sliding, the sharp asperities in the brass would have broken and the surface roughness would be one with large amplitude with smaller peak. Now the stress value in the asperity-base plane is not sufficient to fracture. Now the brass asperity which has partially entered the valley created by the removal of polyethylenimine pushes the carbon fiber. Since carbon fiber is partially open (polyethylenimine covering the fiber is partially removed) it bends and later cracks. Fiber bending may be also due to a number of debri paticles getting entrapped between fibers and they getting compacted due to compressive loading. Cracking in the long microstructural features with sharp edges is reported by Prasad during sliding wear of cast iron [9]. During this there will be carbon fiber- polyethylenimine matrix debonding. Now wear debris will have brass, polyethylenimine and carbon fiber fragments. Since sliding is under dry conditions, the progress of further damage is also affected by these debris. Also, debonding at the polyethylenimine -carbon fiber interface will increase the cracking tendency of fibers. Once fibers cracks, the resistance of the fiber for further load bearing and crack resistance drops [10]. Wear debris generated on the sliding surface must be removed. Otherwise they may induce severe damage to the contact surface [11,12]. Unfortunately, the extent of debris removal is not high in heterogeneous materials like composite and hence damage also considerable. The inconsistency in the trend as shown in table.2 may be due to different amounts of debris collected on the sample surface. Hence weight loss may not be a good parameter.

5. Conclusions

The material damage increases with increase in the pressure. The damage is mainly through the removal of polyethylenimine present between the fibers, as well as fiber breakage. Roughness of the composite increases due to the sliding damage. The wear debris consists of brass particles, polyethylenimines and broken carbon fibers.

References

[1] Ramalho A, Miranda J.C, Wear, Tribological characterization of electroless NiP coatingslubricated with biolubricants, Wear, 2007, vol: 263, 16: 1-6, pp. 592-597.

[2] Friedrich K, Hager A.M, Recent advances in polymer composites tribology, Wear, 1995, vol: 19, pp.139-144. doi:10.1016/0043-1648(96)80012-3.

[3] Sarı N, Sınmazçelik T, Erosive wear behaviour of carbon fibre/polyetherimide composites under low particle speed, Materials & Design, 2007, vol: 28, Issue 1, pp. 351-355, doi:10.1016/j.matdes.2005.05.014 Elsevier.

[4] Zum Ghar K H, Microstructure and Wear of Materials, 1987, Elsevier Publ., Amsterdam. PUB TYPE: Book (ISBN 0444427546), PUB ID: 102-554-778 (Last edited on 2002/02/27 18:07:33 US/Mountain).

[5] Nosonovsky M, Bhushan B, Scale Effect in Dry Friction During Multiple-Asperity Contact. Journal of Tribology, 2005, vol : 127: Issue 1, 37 (10 pages) doi:10.1115/1.1829722.

[6] Kato K, Wear in relation to friction - a review, Wear, 2000. Vol: 241: 2, pp. 151-157, doi**:** 10.1016/S0043-1648(00)00382-3.

[7] Masen M A, de Rooiji M B, Schipper, Micro-contact based modelling of abrasive wear. Wear. 2005. vol : 258 : (issues 1-4), pp.339-348. ISSN 0043-1648.

[8] Torrance A A, Modelling abrasive wear, Wear 2005, vol: 258, pp. 281-293, doi:10.1016/j.wear.2004.09.065.

[9] Prasad B K, Sliding wear response of a cast iron under varying test environments and traversal speed and pressure conditions, Wear, 2006, vol: 260: Issues 11-12, pp. 1333-1341, doi:10.1016/j, wear.2005.09.017.

[10] Yuan Q, Meng H Yiu-Wing M, Lin Y, Resistance Welding of Carbon Fiber Reinforced Polyetherimide Composite. Journal of Thermoplastic Composite Materials, 2001. vol: 14: pp. 2-19, doi: 10.1106/XF4F-6NEH-9KGN-1Y4R.

[11] Ling W, Ji-xin C, Ming-yue L, Baoa, and Zhou Y, Reciprocating friction and wear behavior of Ti3AlC2 and Ti3AlC2/Al2O3 composites against AISI52100 bearing steel. Wear, 2009, vol: 266, pp.158-166, Issues 1-2, 5. doi 10.1016/j, Wear.2008.06.009.

[12] Bijwe J, Rattana R, Influence of weave of carbon fabric in polyetherimide composites in various wear situations. Wear, 2007, vol: 263, pp. 984-991, Issues 7-12 doi:10.1016/j, wear.2006.12.030.